



# THE UNIVERSITY *of* EDINBURGH

## Edinburgh Research Explorer

### Building 'mass' and 'momentum'

**Citation for published version:**

Shen, X 2018, 'Building 'mass' and 'momentum': A latecomer country's passage to large technological systems – the case of China', *Technology Analysis and Strategic Management*.  
<https://doi.org/10.1080/09537325.2018.1519184>

**Digital Object Identifier (DOI):**

[10.1080/09537325.2018.1519184](https://doi.org/10.1080/09537325.2018.1519184)

**Link:**

[Link to publication record in Edinburgh Research Explorer](#)

**Document Version:**

Peer reviewed version

**Published In:**

Technology Analysis and Strategic Management

**Publisher Rights Statement:**

This is an Accepted Manuscript of an article published by Taylor & Francis in Technology Analysis and Strategic Management on 6/09/2018, available online:  
<https://www.tandfonline.com/doi/full/10.1080/09537325.2018.1519184>

**General rights**

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

**Take down policy**

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact [openaccess@ed.ac.uk](mailto:openaccess@ed.ac.uk) providing details, and we will remove access to the work immediately and investigate your claim.



# **Building ‘mass’ and ‘momentum’ - A latecomer country’s passage to large technological systems – the case of China**

Xiaobai Shen

*University of Edinburgh Business School, Edinburgh, the UK*

[Xiaobai.shen@ed.ac.uk](mailto:Xiaobai.shen@ed.ac.uk), +44 131 6503819

## **Abstract**

This paper focuses on how a latecomer country can bring a large (infrastructural) technological system (LTS) to a market already dominated by the entrenched systems of global technology leaders. We construct a conceptual framework, building on Hughes LTS theory (1983) and insights from social studies of technology into the specificities of infrastructural sociotechnical systems to analyse the development of China’s 3<sup>rd</sup> Generation mobile telephony system. We explore the complex dynamics surrounding the distributed governance of innovation, highlighting changes in key system builders. We note the role of the state in addressing critical problems (“reverse salients”), both in terms of aligning players through legitimating and sense-making and also, building the necessary mass and momentum. This includes a more radical reconfiguring of the field to secure the substantial commitments needed to materialise and embed a new LTS infrastructure.

## **Keywords**

Large technological systems/infrastructures, latecomer country, mass and momentum, China, role of the state, distributed governance of innovation

## **1. Introduction**

For the first two generations of mobile telephony, China was merely an adopter of foreign technologies. It had to pay ‘hundreds of millions of dollars’ every year for 2G patent licensing fees (Li 2011:48), in addition to five-hundred billion invested purchasing foreign 2G equipment (Liu 2016). Today, following the success of its third

generation TD-SCDMA (TD-LTE) mobile technology and standards (Stewart, Author, Graham and Wang 2011), China has become a key global player.

Studies of technology catch-up by latecomer countries, deploying different analytical lenses, have reached very different verdicts about the possibility of success and its key determinants, and in particular the role of government. Despite the dominant position favouring laissez-faire approaches,

The rapid development of East Asian economies has presented a challenge to prevalent neoliberal policy perspectives favouring laissez-faire approaches. Scholars from development studies analysing the success of the Asian Tigers and China's achievements have paid specific attention to differences in their development pathways and changes over time (Lall, 2003) and have highlighted the important role played by the state in development. However, there is the need to move beyond general prescriptions and achieve a clearer understanding of what roles the state must play and particular and at what stages in the prolonged technological catch-up process.

Drawing upon science and technology studies (STS), rather than treating technology abstractly as a uniform, generic category, we explore the specificities of large infrastructural technological systems and examine the challenges facing latecomer countries - to catch up in a context dominated by existing international leaders, highlighting particularly the role of the state in system building.

The foundational studies of 'large technological systems' (LTS) were originally developed by Hughes (1983, 1986, 1987; Mayntz and Hughes 1988). This paper integrates Hughes' LTS theory with recent insights from studies of ICT infrastructural technological systems (Aanestad et al. 2007, Pipek and Wulf, 2009, Sahay et al. 2009). We suggest that newcomer countries are beset by enormous challenges and may find themselves locked out of the market by the entrenched technological systems of world

technology leaders. Conventional development approaches, which have tended to focus narrowly on the acquisition of ‘technical capabilities’, fail to see that the main obstacles are typically a mixture of social, economic and political elements (Khanna and Palepu 1997) in addition to simply lacking knowledge, technical capabilities and resources, etc. We draw attention to the diverse roles played by the state, R&D and industrial agents, particularly in relation to LTSs underpinning core infrastructures, such as electricity networks, railroad networks, telephone systems and the internet (Geels, 2004, 2007).

Against a background of many failures and fewer successful cases regarding LTS in newly industrialising economies, this paper analyses the case of China’s development of the TD-SCDMA (TD in short hereafter) 3<sup>rd</sup> Generation Mobile telephony system. We highlight the protracted and convoluted innovation journey, replete with unplanned turns and upheavals resulting from interactions between multiple players with diverging perspectives and commitments. We focus on the governance of these distributed processes of innovation (Acha and Cusmano 2005), highlighting how governance challenges and structures changed at various stages of development (Steen 2011). By re-assessing the process of technology development, we find the most critical point is in the final phase of creating a new social-technical infrastructural ensemble. To implement and mature the new challenger system to the point at which it could compete with incumbent systems of world technology players required the mobilisation of enormous mass and momentum. This was achieved beforehand by radically reconfiguring the structure and dynamics of the telecommunications industry.

We examine a number of closely intertwined social and technical factors that have often been conflated. We apply Hughes’ (19988) concept of “reverse salient” (Hughes 1988), to emphasise the complex temporal dynamics of the changing critical challenges encountered by a latecomer country, and discuss the “mass” and

“momentum” needed at a particular juncture in the pursuit of catch-up goals by a latecomer.

This paper develops a conceptual framework for analysing the challenges faced by a latecomer country seeking to catch-up and build a large telecommunications infrastructural system. We then apply this framework to the case of China’s TD-SCDMA 3G mobile telephony standard, which continues beyond 3G as TD-LTE and 5G.

## **2. Analytical framework: a latecomer’s perspective in the field of large and complex technological systems**

Hughes’ (1983, 1987) large technological system theory was one of the foundational contributions to discussions of the social construction (Bijker et al., 1987) or social shaping of technology (SST) (MacKenzie and Wajcman 1985). A body of subsequent studies has examined the social and technical specificities of different forms of innovation in different contexts. Research highlights the enormous social and technical investments involved in the construction of LTS and infrastructural systems. Once established, the ‘social weight’ behind these entrenched elements makes them very difficult to displace (Collingridge 1980). This can create problems for latecomers. Strategies have been proposed for overcoming such entrenchment – most notably in relation to managing environmental transitions (Rip and Schot 2002, Geels 2004). These accounts have not yet attempted to understand the obstacles besetting latecomer countries developing LTSs; the hurdles that must be overcome at various stages of promoting a challenger technology; and the roles of R&D, industrial players and the state in emerging economies like China in bringing a new technology to market and helping it sustain in a competitive global context.

## **2.1 Large technological systems (LTS)**

Science and technology studies (STS), and in particular the SST perspective, seek to ‘open up the black box’ of technology (MacKenzie and Wajcman 1985) and reveal how the historical context shapes technological development – and may itself be transformed in a process of mutual shaping. The concept of “large technological systems” introduced by Hughes (1983) in his historical studies of the creation of the electric power system in Western countries in the late 19<sup>th</sup> and early 20<sup>th</sup> century and subsequent studies of LTSs (for example, Davies, 1996; van der Vleuten, 2004, 2006, 2009) draw attention not only to obdurate technical challenges but also complex social elements involved in these technologies. They reinforce a central tenet of SST, about the need to treat technologies, especially large complex technological systems, as ‘heterogeneous assemblages’: taking into account the visions and beliefs, the techniques and practices of the various actors involved in the development, implementation, use and governance of an innovation (Williams and Pollock, 2012). In these large complex assemblages, ‘technical’ and ‘social’ elements are profoundly intertwined.

Hughes analysed the development of the emergent electricity system, showing how the process changed over a number of different phases:

- *invention*: the emergence of radical inventions with potential to be key elements of a new technological system;
- *development*: how a nascent system is adapted to the economic, political and social world;
- *innovation*: the changes necessary for bringing the technology to the market;
- *competition, growth and consolidation* as the new system struggle to survive and strengthen its market position in competition with other technological systems.

Hughes defines these phases to distinguish their particular features, whilst noting that these phases may overlap and do not necessarily follow a sequential, linear order. The underlying point remains: building large complex technological systems may require a number of system builders able to mobilise and deploy the different sets of capabilities of players needed in specific phases of the development.

Scholars of LTS share with others in technology and innovation studies an understanding that invention does not necessarily lead to innovation. Rather, inventor-entrepreneurs (Hughes, 1983) and their associates must embody in their invention ‘the economic, political, and social characteristics that it needs for survival in the use world’ (Hughes, 1987: 62). Hughes places key (individual/ institutional) stakeholders - such as inventors, investors, policymakers - at the heart of the analysis of sociotechnical system development, highlighting the role of system builders (SBs). The ‘system builder’ roles need to change in order to overcome diverse “reverse salients” between phases. For example, system builders in the development and innovation phases, *inventor-entrepreneurs*, may need to step aside and be replaced by *manager-entrepreneurs* in later phases (Hughes, 1983, p. 67-68).

Hughes introduces the concept of ‘momentum’ to capture the influence of elements such as vested interests, fixed assets and sunk costs. This metaphor denotes that LTSs have a ‘mass’ of sociotechnical and organisational components and that together must be given velocity and direction (Hughes, 1983: 76. See also Tidd 2010; Schubert et al. 2013). This is a dialectical view of technological system-building whereby system builders construct and configure the system, which, in turn, impact on the LTS and the society in which it is embedded.

Hughes uses the military term ‘reverse salient’ (further developed in Mayntz and Hughes 1988) to characterise the way in which critical unsolved problems hold up the

advancing ‘front’ of technology development and then become the focus of innovative effort.

## ***2.2 Sociotechnical specificities of large infrastructural technological system - lock-in effects***

Highly generalised accounts of technological innovation often misleadingly fail to differentiate between different technologies. LTSs like mobile telephony, forming the core of highly complex telecommunications infrastructures, have a number of distinctive features.

First, most large complex technological infrastructures do not emerge *de novo* (Star and Ruhleder 1996). They are never built from scratch. Rather, they build on, extend and enhance existing structures (Aanestad et al. 2007). Thus, they are strongly path-dependent (Sahay et al. 2009), erected on the foundations of previous innovation efforts and contexts. Studies of ICT infrastructural systems have drawn attention to the *installed base*, encompassing existing components – such as technology artefacts, standards, organisational structures, business practices, behavioural patterns, and social preferences of the users (see Rönnbäck et al. 2006) – that shape further development trajectories and socio-technical regimes (Geels 2004).

The notion of installed base draws attention to political and institutional settings and the rules and routines that players follow in conducting their activities at a particular time and social space. They may prove the most ‘weighty’ and intractable elements of infrastructural ICT systems (Edwards et al. 2009), as these elements are deeply embodied in prevailing technological systems - reflecting institutional power structure among networks of players. We categorise players into three types: governmental, industrial and specialist ‘technical’ communities including R&D. They shape the future direction of development of the technological system. These deeply-



rooted sociotechnical entrenchments faced by new entrants from latecomer countries have often been overlooked, despite their enormous influence.

Furthermore, these infrastructural systems are ‘networked technologies’ (Cowan, 1992), which exhibit what economists have described as powerful ‘network externalities’ (Katz and Shapiro, 1986, 1992, 1994, Shapiro and Varian 1999) - whereby adding new users increases the value of the system to each user without proportionate additional cost. These network effects reinforce ‘lock-in’: giving existing operators with established technologies enormous economic advantages.

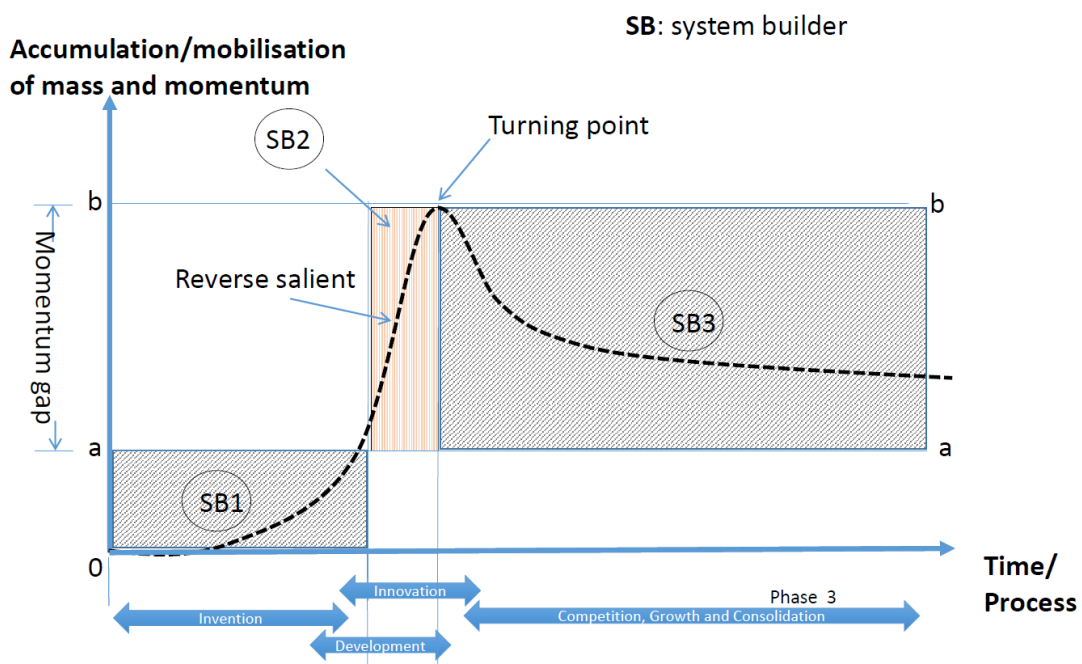
These network effects are particularly pronounced with network technologies where interoperability and interconnectivity between components and systems are required. This manifests in the standardisation of ICT infrastructural technological systems. ICT standardisation can be seen as defining the assembly of existing and emerging components and systems with the social and political interests inscribed in them (Chillundo and Aanestad, 2005). Organisations may seek to package their patented component technologies within prospective standards. When standards are set and adopted within ICT infrastructures, they may become *essential* intellectual property (IP). The IP owners of the technologies packaged within the standard are guaranteed effective monopoly within those systems, thereby generating significant economic gains. The growing volume of patenting activity associated with standards means that latecomer firms and emerging economies can be locked out of the developers’ club and ‘trapped’ into merely playing a role as technology receivers: the more they resort to globally standardised systems, the greater the licensing fees they must pay.

The standardisation of network technologies often becomes a battleground, shaped by the vested interests of powerful stakeholders (Brunsson, Rasche and Seidl, 2012; Brunsson and Jacobsson, 2000; van den Ende, van de Kaa, den Uijl and de Vries,

2012). Considerable mass and momentum are needed to overcome lock-in and the entrenchment of existing providers (Geels 2007).

### 2.3 Analytical framework for a latecomer country

We build a generic model based on Hughes and STS. This is summarised in Figure 1, which seeks to capture the changing dynamics and system-building role for a latecomer country in creating a large infrastructural technology.



**Figure 1. Challenges for late comers**

Some flexibility is required when applying the LTS framework to the position of latecomers in the development of a large ICT infrastructural system, particularly in relation to Hughes' analyses of electricity system development from its earliest stages. We divide the process into three phases. The first phase involves both creating a new prototype technology and securing (both national and international) regulatory approval. It is impossible for a latecomer to "invent" a wholly novel ICT infrastructural system from scratch. Many technical and institutional elements are already in place from entrenched competitor systems – accentuated by the imperative for technical

interoperability and connectivity; the direction of innovation is relatively established. The key uncertainties are whether the challenger can survive/prevail in the face of entrenched market leaders. The invention stage overlaps and becomes intertwined with development and innovation. In this context the system builder needs to transcend the capabilities possessed by individual industrial and R&D players. The SB role requires gathering sufficient human and material resources and mobilising them in the same direction whilst confronting political and institutional barriers. These become salient in the second phase identified in this model where specific reverse salients need to be addressed through activities of sense-making, coordination and ultimately regulation and investment.

A latecomer must develop a large and complex technological infrastructure and bring it to those (unattempted or emerging) markets not yet occupied by established players. In this third phase, the crucial challenge, as characterised by Geels (2004, 2007), is to embed a promising ‘niche’ solution into the broader socio-technical regime to the point that it can compete with the entrenched systems of world leaders, who are already well positioned technologically and institutionally within the power structure of the international communities. Entering such a market demands an enormous force to bring a challenger system to the point that it can compete and bring in revenue. Many technological systems developed in newly industrialised countries have failed to reach the market with sufficient momentum (see e.g. Park, Kim and Nam, 2015, Lee, Mani and Mu 2012). As we explore below this in the case of TD in China this was achieved by a significant reconfiguration of the socio-technical regime that transformed the structure and dynamics of the telecommunications industry and market.

Figure 1 is constructed to illustrate the process with three phases staged by different “system builders” (Hughes’ term). It highlights the rapid mobilisation of

“mass” and “momentum” needed to enter the market in the overlapping phase of “development” and “innovation” and compete and earn revenue. We derive from Hughes’ LTS theories the concept of ‘momentum gap’ to elaborate the need to tackle various “reverse salients” to bring a prototype technology to the market. The “momentum gap” highlights two types of deficiencies in terms of lacking human and non-human resources and of the common goals/priorities of actors involved.

Through this framework we unpick the diverse and changing “reverse salients” that must be overcome. These include, first, resource mobilisation to create sufficient “mass” including monetary and material inputs, the endeavours of governmental, R&D and industrial players across the entire supplier chain. Second is an effort of sense-making needed to create meanings and legitimations that would capture the subjective goals of all in the “networks of agents” (Carlsoon and Stankiewicz, 1991, cited in Geels 2004), projecting a promising future “landscape” (Geels 2007) to convince them to move in a common direction. The insertion of developing economies in the Global Value Chain (Ernst and Kim 2012) means that many players from latecomer countries already belonged to the value chains/networks of the entrenched socio-technical regimes. Because of the complexity of modern ICT infrastructures, the new “networks of agents” required for a challenger system must go beyond the national and include overseas players. Key players in a latecomer economy may need to be weaned from the value chains of entrenched global players towards challenger technologies. That is to transform the existing dynamics of the market and to construct a new competitive environment.

### **3. The evolution of China’s mobile technology capabilities**

The primary data sources were created through an investigation conducted in 2008-2010 funded by European Union under 7<sup>th</sup> Framework Programme (see Stewart et al. 2011;

Author et al. 2013; and Author and Naughton 2013).<sup>i</sup> The salience of the TD-SCDMA case and the sustained debates within China about its costs and indigenouslyness has thrown up an extensive body of grey literature, which provides rich resources for documenting this complex history and has also stimulated a number of independent analyses including Li (2009 in Chinese), Xia (2011), Yu (2011), Gao and Liu (2012) and Gao (2014). Though drawing attention to the indispensable role played by the state in these developments (Liu et al. 2011, Author and Naughton 2013, Gao 2014,) these analyses also highlight the pitfalls and uncertainties surrounding state intervention (Yu 2011, van de Kaa et al. 2012). The debate around 3G TD-SCDMA continues. We have therefore reanalyzed this body of evidence to seek a more thorough understanding of the complex dynamics and varying roles of the state in the distributed governance of innovation (Suh, 2014). We discuss the kinds of state intervention that may be required at particular junctures and contexts.

### ***33.1 The dynamics of TD system building***

Initially, Datang, an R&D firm affiliated with the Chinese Academy of Telecommunications Technology (CATT) under the Ministry of Posts and Telecommunications (MPT), successfully led the development of TD-SCDMA to become one of the three third-generation (3G) mobile telephony standards in the world.

Datang first recruited an overseas Chinese firm- Cwill (Author paper 2013) which possessed a core subsystem needed for TD (Author et al, 2013). Extending this strategy, it established collaboration with world-leading switching technology firms: Siemens and Alcatel-Shanghai Bell (Alcatel-Lucent 2010). During this period it gained political and financial support from its parent institution, CATT and MPT. R&D funds came not only from the MPT and subsequently the Ministry of Information Industry (formed by the merger of MPT and Ministry of Electrical Industries), but also from the State

Science and Technology Commission (which later became Ministry of Science and Technology - MOST). In June 1999, with the support of the Chinese Government, Datang Group put forward its TD-SCDMA mobile system for approval by the International Telecommunications Union (ITU), the United Nations body responsible for telecommunications technology standards. In May 2000, the ITU approved three international 3G mobile telephony standards: two established standards - the US-centred CDMA-2000 and the Europe-centred WCDMA standards - and the Chinese newcomer TD-SCDMA. Technically, TD is based on Time-Division Duplex (in contrast to the Frequency-Division Duplex that the US and European systems are based on). The advantages and disadvantages of Time- versus Frequency- Division based mobile technologies are a subject of continuing debate amongst expert communities. In discussions of future 5G mobile standards, TD is described as better in terms of energy and frequency spectrum saving, effective in Multi-input-multi-output, whilst disadvantaged by the lack of prior established commercial interest.<sup>ii</sup>

Datang's success culminated in the approval of the TD standard by the ITU. However, when facing the subsequent challenge of bringing TD from a prototype to a working product that could compete with incumbent systems, Datang found itself out of its depth, even with existing governmental support, in the face of a web of deeply intertwined and intractable problems.

When ITU approved TD, it was still an immature technology; a newcomer which needed to make its way to the market in competition with the American CDMA-2000 and European WCDMA. The latter were both mature products already operating in their respective markets, building upon an installed base of 1-2G systems. China's 1-2G mobile telephony was based upon the European standard. In the absence of a domestic 3G mobile infrastructure at home, many Chinese firms were producing

CDMA (US standard) and WCDMA (European standard) products ranging from handsets to large network equipment for the global market. Strong players like Huawei and ZTE had already invested to develop and supply their own 3G products to the American and European markets. China's (1-2G) mobile network service providers including China Mobile were actively testing 3G network services based on those matured standard systems. All these factors meant that no firm would commit significant investments in TD. TD was then too risky for them.<sup>iii</sup>

Within China there were sharp differences in view about whether it would be better to exploit available foreign technologies than invest in an 'indigenous' technology that was not yet market-ready. Critics argued that only a small portion of TD's IP (perhaps as low as 7%) was Chinese (Author paper 2013). Given the situation, Datang's initial grounds for developing "indigenous" standards became disputable.

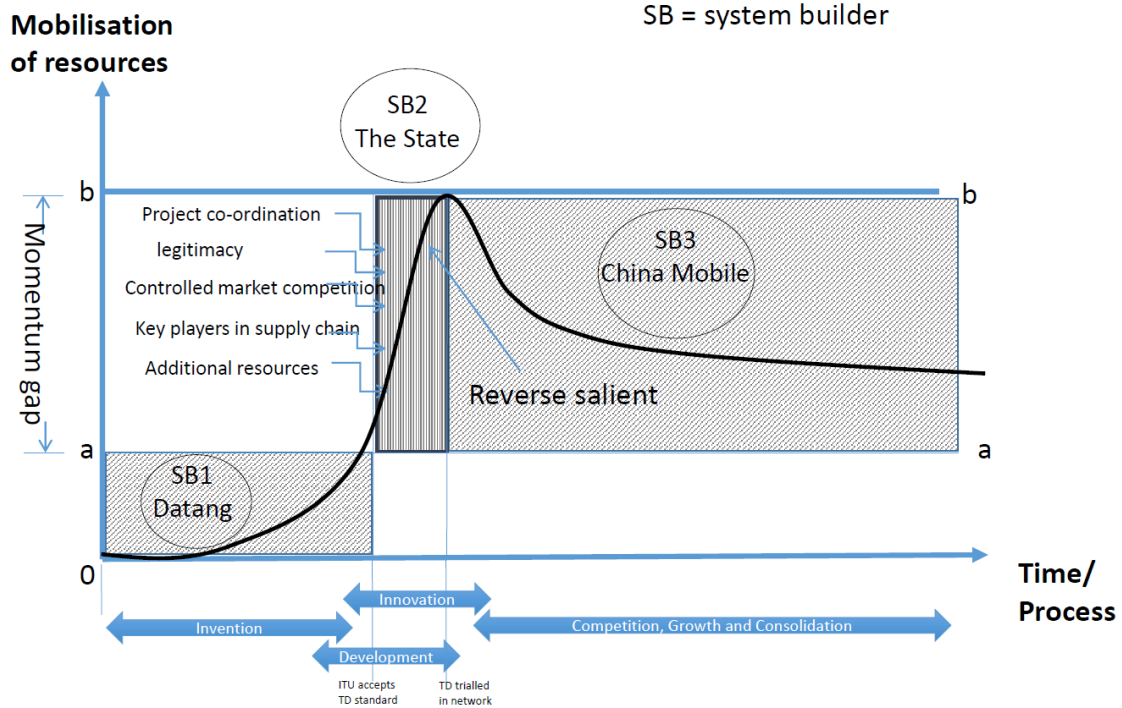
After the TD standard was accepted by the ITU, the whole world awaited China's decision. Powerful global players pressed the Chinese government to promise 'technology neutrality' between the three 3G mobile standards approved by the ITU. At the same time, domestic players were looking at the government for responses.

The eventual action by the government, though delayed, surprised everyone for its decision to adopt all three 3G standards and for the scale and sophistication of government intervention at multiple levels (for details, see Stewart et al. 2011 and Author et al. 2013). Revisiting the state actions in a nutshell, a new super-ministry, the Ministry of Industry and Information Technology (MIIT) was formed, merging two rival ministries to overcome internal organisational frictions.<sup>iv</sup> Shortly afterwards, the National Development and Reform Commission (NDRC), the Ministry of Finance and MIIT jointly issued an 'Announcement on Deepening the Reform of the Structure of the Telecommunications Sector' (23 May 2008). This document singled out China Mobile

for criticism for its sceptical attitudes towards TD and stated that China Mobile had no choice other than to devote itself to the implementation of TD-SCDMA. The new minister, Li Yizhong, held a public meeting with TD-SCDMA technical experts and discussed further advances of TD-SCDMA's implementation. The president of China Mobile made a sharp U-turn, declaring that China Mobile will 'make every effort' to ensure excellent TD-SCDMA service in time for the Beijing 2008 Olympic games! Under the convenorship of the NDRC, directly led by the State Council, MIIT and other related government departments formed a cross-ministry coordinating group to oversee the implementation of thirty-four TD-related special work packages. By August 2008 the first licences for TD-SCDMA handset production were issued by the MIIT, and plans for commercialisation were laid out.

A major structural reform/reorganisation was undertaken in the telecommunications sector. The six existing state-owned operators were consolidated into three key players to compete in all telecommunications services – one for each of the international standards. MIIT issued three 3G licences in early 2009: China UNICOM was awarded the European-centred WCDMA standard, China Telecom the 'US' CDMA standard, and China Mobile, the largest player, was given the challenge of bringing to market services based on the home-grown Chinese TD-SCDMA standard. Figure 2 summarises the process.





The development of TD was not a straightforward outcome of top-down state planning but emerged through protracted and complex, multi-level negotiations between diverse players. In the initial phase integrating invention with innovation and development, the R&D oriented enterprise, Datang was the key player. The particular challenges it faced as a system builder, went far beyond its possession of specialist technical knowledge in the field. No less important was its ability to form partnerships and alliances with various industrial players including not only domestic but international ones. Some of the alliances cut across, and were potentially in conflict with, the web of interests in the existing socio-technical space of incumbent competitor systems. Datang also had to play an effective role in the political domain in order to gain support from the array of governmental players.

### ***3.2 Momentum gap and the role of the state***

In the face of the entrenched technological systems of powerful global incumbents, securing ITU approval did not guarantee the survival of TD, nor help

Datang and other Chinese industrial players to secure a level-playing position in the market and an equal status in the international technology communities. TD's success or failure would have a significant consequence to China, if it wanted to avoid being locked-out of the mobile technology innovation arena and having to continue to pay hundreds of billions in licensing fees to the world leaders. China needed to find a way to develop the embryonic 3G TD standard technologies to the point it could survive and consolidate itself in a market dominated by the entrenched systems of global players. This was a new game where a player like Datang did not have the considerable "weight" needed to get the world to budge even a little. The size of the Chinese market provided exceptional opportunities and was the key to securing commercial support from industry players and bringing TD to the market. However mobilising this mass and momentum was achieved in this case by radically reconfiguration of the telecommunications industry and the market, to create the conditions in which TD was able to grow, mature and compete with entrenched competitors.

There was a "momentum gap" to overcome (see Figure 2), where the state had to step in. This was not only in its overt stance that supported TD, but through also a range of direct and indirect actions, which brought significant changes in the field. Two key programmes secured the foundations for the long-term development of TD and boosted the morale of the stakeholders involved from the R&D, industry and government. State intervention brought together all R&D and industrial players along the entire supply chain, from suppliers of various component technologies to core network capabilities, RAN (radio access network), terminal, mobile handset systems, chips, testing instrument, antenna and direct amplifier stations, etc. The TD Industrial Alliance established in 2002 received behind the scenes support from the state, which

provided political and financial resources needed for the project (for details see Stewart, et al. 2013). The forcible recruitment of China Mobile into the Alliance in 2008 completed the supply/value chain.<sup>v</sup> China Mobile immediately became a member of the Board of Directors and took over leadership in the industrialisation/commercialisation of TD. China Mobile took over as the TD system builder in the third phase. The leverage could best utilise for accumulating ‘mass’ and ‘momentum’ was the size of the Chinese market (which since 2003 had possessed the world’s largest number of consumers).

China Mobile was chosen deliberately by the state, which had created two significant effects. As China Mobile was, at the time, the most successful service operator with the largest user-base in the market and deepest pockets. Shifting its allegiance from WCDMA and CDMA to TD dramatically weakened the commercial prospect of competitor systems in the Chinese market and changed the dynamics in the field. With the track record of commercial business experiences, China Mobile was able to turn TD development plans into practical business actions, including the development of handsets, terminals and network equipment and testing and improving the quality and launching services.

As Hughes pointed out, the diverse vested interests of different players often become the thorniest obstacles, preventing the large array of actors across the supply chain from forming a “mass” that could achieve “momentum” and work effectively in the same direction.

These issues were key in the process of TD development. Many industrial players were attracted to Chinese 3<sup>rd</sup> generation mobile infrastructure technologies. However, they had to weigh the pros and cons, and consider the risks if they invested in a new technology which was far from mature compared to the US and European ones.

To compound the problem, many Chinese firms, such as Huawei, ZTE and others, had already become involved in the already established global value chains (Ernst and Kim 2002), offering low-priced component technologies (handsets; exchanges) for incumbent mobile systems.

In contrast to stereotypical portrayals of the homogeneity of views in China, there have been sharp controversies over TD expressed in the media, academia as well as government. TD's 'indigenouness' was severely challenged for some time. Datang was criticised for pursuing its vested interests and reputation while wasting huge amounts of money and resources on a technology that had limited claims to be "indigenous". Like other infrastructural technologies, TD-SCDMA did not simply emerge *de novo* (Aanestad et al. 2007). Rather, it built upon various essential components and sub-systems, including, for example, some historical patents from its US CDMA rival. Even the idea of using TD (time-division) instead of FD (frequency division) that underpins other two rival standards originally came from Siemens (Stewart et al. 2011)! For consumers, however, the 'indigenouness' of technologies may not be meaningful at all. Interoperability of TD, WCDMA and CDMA2000 would be much more beneficial for mobile users.

The dispute between supporters and opponents of TD-SCDMA regarding its 'indigenouness' continued during the whole development process but became intense at various points (Stewart et al. 2011). Without the public support of the state at the highest level, the whole programme could have been jeopardized. The state was the only player able to set at ease the concerns of these industrial players, and change the dynamic amongst them from competition to collaboration over TD.

### ***3.3 Distinctive features of state intervention in the Chinese contexts***

Writers have noted the indispensable role (Gao 2014; Liews 2005) played by the state in the development of TD. However, it is unhelpful to over-generalise the role the state is required to play over different technologies, moments and contexts. We observe particular features of Chinese state intervention, which have to be understood in the Chinese context.

There is a popular misconception that the Chinese Government is a uniform entity. The TD case demonstrates that various government departments had diverging perspectives and acted differently on this issue. The Ministry of Science and Technology (MOST), which provides grants for new science and technology development in supporting R&D institutions like Datang, had always been a keen promoter of TD. The Ministry of Information Industries in contrast prioritised overall industrial growth, for which meeting domestic demand came first, and “indigenouslyness” secondary (author et al. 2013). In a hierarchical political structure, the State Council has power and authority to coordinate, despite the diverse goals of individual ministries, convening national strategies and restructuring the ministries when necessary.

The TD case displays also some subtleties of its interventions. The final national strategy of TD development perhaps uniquely guaranteed a space for the US and EU standards alongside the Chinese. The mobile sector was restructured to create three large state operators, each with a license for a particular system, to compete head-on in the market on the national network in a seemingly level playing field.

This draws our attention to distinctive features of intervention by the Chinese state. We note the cautious and flexible way in which the state interpreted national interest. Initially cautious about adopting a ‘techno-nationalist’ stance (Suttmeier and Yao 2004) (in contrast to accounts by Western lobbyists), its eventual position struck a

balance between a variety of perspectives. Adopting all three mobile systems was economically inefficient. However installing TD alone would be risky and might isolate China from technology development in a world where interoperability and connectivity are essential. A longer-term consequence has been that Chinese players, for many practical reasons, have moved swiftly to next-generation technologies including TD-LTE and 5G mobile technologies and are now amongst the leading global players in the field.

Second is the state's ability to intervene. This revolves around its ability to coordinate across a number of spheres (e.g. public research, frequency allocation, standardisation) coupled with the considerable authority vested in the Chinese state. At key decision-making junctures, major R&D and industrial actors, whether state-owned or private, looked to the state for answers.<sup>vi</sup> We also note that at key moments when particular governmental actors encountered limits in their ability to intervene, a higher level actor would be brought in to form new national strategies. In the case of TD, moving into the third phase involved a more profound reconfiguration of the socio-technical infrastructural ensemble was required. We use the terminology of reconfiguration of the ensemble, rather than the related but more generic concept of regime change (Geels 2004), to unpick specific changes in innovation dynamics in the TD case. This included successive shifts in the lead system builder role, first, from innovation players to governmental and then to industrial players. The substantial investments needed to physically materialise and mature the prototype infrastructure to the point where it could compete in a market dominated by incumbent systems of world technology players called for mobilisation of substantial mass and momentum and was achieved a transformation of the structure competitive dynamics in China's telecommunication industry.

Though concerted state intervention proved crucial, particularly in the case of a latecomer economy, this is by no means a story about unilateral action by powerful state structures – quite the reverse. The state could not ignore the close interconnections between global arrays of players involved in creating interoperable elements that are woven into infrastructural LTS. This was displayed in the protracted debate over the pursuit of TD, in which government intervention was delayed to allow deliberation and adjustment of its own structures and strategies.

#### **4. Conclusion**

Large-scale ICT infrastructural technologies embody complex social elements rooted in the relations between stakeholders and also the power structures of the socio-technical worlds in which the innovation processes take place. A latecomer country faces multiple challenges as new hopeful systems must confront the entrenchment of already-established systems. The state was called in to play a key role at the juncture of bringing prototype technologies to the stage of finished products that can operate in the network infrastructure and compete in the market. It was beyond the capacity of individual R&D or industrial players to overcome the multiple interlocking ‘reverse salients’ that constituted the ‘momentum gap’. What was lacking was not just resources, but also effective governance, mobilising and channelling resources and players towards the same goals. This study shows the importance of the relationship between R&D and industrial players and the state, the distributed governance of innovation: aligning and mobilising each other according to the circumstances and needs arising at particular times.

This observation about the key role played by state intervention may need to be considered in relation to the specific context and the practical functions such intervention fulfils. Some elements may well be specific to the particular historical

context and may disappear as China's social and economic transition continues over time. Moreover, these observations pertain particularly to distributed innovations in large-scale, physical infrastructures – whose roll-out requires enormous investments (see also Suh, 2014). A corollary of our emphasis on sociotechnical specificities is that other technologies may exhibit different innovation dynamics and associated governance challenges due to differences in scale, complexity, levels of investment required, etc. (particularly, for example, software technologies and internet services). These observations highlight potential limitations of this paper. This paper arose from an effort to examine features of a number of recent episodes in which China had sought to develop key ICT capacities. The goal was to develop and test a model, based upon Hughes (1988), through retrospective reanalysis of historical cases (only one of which is presented here). Issues arise about generalizability from particular cases, particularly in retrospective studies. A key priority will be to conduct additional historical, and if possible, longitudinal studies, through which the complex flows of influence in system building in different settings may be explored.

Lessons may, however, only become apparent in the longer-term. Today, TD-SCDMA has been more or less replaced by TD-LTE and other new standards. However, though entrenching TD in the market required costly efforts, the experience Chinese players gained in exploiting R&D and in standardisation has allowed them to become key players in the international club of mobile technology developers, that would otherwise have continued as an exclusive preserve dominated by players from America and Western Europe.

## References

Aanestad, M. Monteiro, E. and Nielsen, P. (2007) Information infrastructures and public goods: Analytical and practical implications for SDI. *Information technology for development*, 13 (1), 7-25.



- Acha, Virginia and Lucia Cusmano (2005), 'Governance and co-ordination of distributed innovation processes: patterns of R&D co-operation in the upstream petroleum industry', *Economics of Innovation and New Technology*, 14 (1-2 – special issue on Microeconomics and Innovation)
- Alcatel-Lucent (15/2/2010) Alcatel-Lucent achieves record speeds on World Expo China 2010 TD-LTE network. Press Release. <http://www.alcatel-lucent.com/wps/portal/newsreleases>.
- Bijker, W. E. et al. (eds.) (1987), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (pp. 51-82). Cambridge, Mass.: MIT Press.
- Brunsson, N., and Jacobsson, B. (2000) *A World of Standards*, New York: Oxford University Press.
- Brunsson, N., Rasche, Andreas, and Seidl, David (2012) The Dynamics of Standardization: Three Perspectives on Standards in Organization Studies. *Organization Studies*, 33 (5-6), 613-632.
- Collingridge, David (1980) The social control of technology. London: Frances Pinter
- Cowan, R. (1992) High Technology and the Economics of Standardization in M. Dierkes and U. Hoffman (eds.), *New Technology at the Outset: Social Forces in the Shaping of Technological Innovation* (pp. 279-300). Frankfurt/Main: Campus Verlag.
- Davies, Andrew (1996) Innovation in large technical systems: the case of telecommunications. *Industrial and Corporate Change*, 5 (4), 1143-1180.
- Fransman, Martin (1990) *The Market and Beyond: Cooperation and Competition In Information Technology In The Japanese System*, Cambridge: Cambridge University Press,
- Gao, Xudong, and Liu, Jianxin (2012) Catching up through the development of technology standard: The case of TD-SCDMA in China. *Telecommunications Policy*, 36 (7), 531-545.
- Gao, Xudong, (2014) A latecomer's strategy to promote a technology standard: The case of Datang and TD-SCDMA. *Research Policy* 43, 597– 607.
- Geels, F. W. (2004) From sectoral systems of innovation to socio-technical systems Insights about dynamics and change from sociology and institutional theory, *Research Policy*, 33, 897–920.

- Geels, F. W. (2007) Transformations of Large Technical Systems: A Multilevel Analysis of the Dutch Highway System (1950-2000) *Science, Technology, & Human Values* 32(2) 123 - 149
- Graham, Ian, Graham Spinardi, and Robin Williams, (1996) 'Diversity in the emergence of electronic commerce' *Journal of Information Technology*, 11 (1), pp. 161 - 172.
- Hughes, T. P. (1983) *Networks of Power: Electrification in Western Society, 1880-1930*. Baltimore, MD and London: Johns Hopkins University Press.
- Hughes, T. P. (1986) The Seamless Web: Technology, Science, Etcetera, Etcetera. *Social Studies of Science*, 16 (2), 281-92.
- Hughes, T. P. (1987) The Evolution of Large Technological Systems, in W. E. Bijker et al (eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (pp. 51-82). Cambridge, Mass.: MIT Press.
- Katz, M. L. and Shapiro, C. (1986) Technology Adoption in the Presence of Network Externalities, *Journal of Political Economy*, University of Chicago Press, 94 (4), 822-41.
- Katz, M. L and Shapiro, C. (1992) Product Introduction with Network Externalities, *Journal of Industrial Economics*, Blackwell Publishing, 40 (1), 55-83.
- Katz, M. L and Shapiro, C. (1994) Systems Competition and Network Effects, *Journal of Economic Perspectives. American Economic Association*, 8 (2), 93-115.
- Khanna, T., & Palepu, K. (1997). Why focused strategies may be wrong for emerging markets. *Harvard Business Review*, (1997 July-August) 41-54.
- Lall, Sanjaya (2000) National strategies for technology adoption in the industrial sector: Lessons of recent experience in the developing regions. Background Paper for *Human Development Report 2001*, UNDP.
- Lall, Sanjaya (2003) Reinventing industrial strategy: The role of government policy in building industrial competitiveness *QEH Working Paper Number 111* (QEHWPS111), <http://www3.qeh.ox.ac.uk/pdf/qehwp/qehwps111.pdf>
- Lee, K., Mani, S. and Mu, Q. (2012) Explaining divergent stories of catch-up in the telecommunication equipment industry in Brazil, China, India and Korea, in F. Malerba and R. Nelson (eds), *Economic Development As a Learning Process*, (pp21-71), Cheltenham, UK and Northampton, MA, USA: Edward Elgar.

- Li, S., (2009) TD-SCDMA: *Third Generation Mobile Communications System. The Ren-min Post and Telecommunications Press* (in Chinese).
- Li, Daitian (2011) *Evaluating the Catching-up Process of China's Mobile Communication Industry*, Master of Science Thesis, KTH Industrial Engineering and Management: Stockholm, Sweden [INDEK 2011:103]
- Liew, Leong, (2005) China's Engagement with Neo-liberalism: Path Dependency, Geography and Party Self-Reinvention. *Development studies* 41 (2), 331 – 352.
- Liu, Feng-chao, Simon, Denis F., Sun, Yu-tao and Cao, Cong (2011) China's innovation policies: Evolution, institutional structure, and trajectory, *Research Policy*, 40, 917-931.
- Liu, Jing (2016) The provoked ongoing debate after the partial withdraw of TD-SCDMA from the mobile network (TD-SCDMA 部分基站退网为何再次引发价值争论 in Chinese), China Daily of Electronics, telecommunication forum, 2016-03-18.
- MacKenzie, Donald and Judy Wajcman (eds) (1985), *The Social Shaping of Technology: or how the refrigerator got its hum*, Milton Keynes : Open University Press.
- Mayntz, R. and Hughes, T. P. (1988 eds.) *The development of large technical systems*. Boulder, CO, USA: Westview Press.
- Park, J., Kim, S. and Nam, C. (2015) Why has a Korean telecommunications technology failed: A case study on WiBro. *Telematics and Informatics*, 32 (4), 603-612.
- Pipek, V. and Wulf, V. (2009) Infrastructuring: Toward an Integrated Perspective on the Design and Use of Information Technology. *Journal of the Association for Information Systems*, 10 (Special Issue) 447-473.
- Rip, Arie and Schot, Johan (2002) 'Identifying Loci for Influencing the Dynamics of Technological Development' Chap 5, pp. 155 – 171 in Sørensen, Knut H. and Williams, Robin (eds) *Shaping technology, guiding policy : concepts, spaces, and tools*, Aldershot: Edward Elgar
- Rönnbäck, L., Holmström, J., Hanseth, O., Borg, T., Frykman, A. and Thomsson, S. August (2006) Changing the installed Base: Exploring IT integration challenges in the process industry, August, Denmark: Paper presented at the 29th

- Information Systems Research Seminar in Scandinavia (IRIS 29): Paradigms Politics Paradoxes, LO-Skolen.
- Sahay, S. Aanestad, M. and Monteiro, E. (2009) Configurable Politics and Asymmetric Integration: Health e-Infrastructures in India. *Journal of the Association for Information Systems*, 10 (Special Issue), 399-414.
- Shapiro, Carl and Varian, Hal R. (1999) Art of Standards Wars. *California Management Review*, 41 (2), 8-32.
- Schubert, C., Sydow, J., Windeler, A. (2013) The means of managing momentum: Bridging technological paths and organisational fields, *Research Policy* 42, 1389–1405.
- Author (1999) *The Chinese road to high technology: A Study of Telecommunications Switching Technology in the Economic Transition*, Houndmills: Macmillan Press; New York : St. Martin's Press.
- Author, and Naughton, Barry (2013) The power of ‘a visible hand’ to the building of innovation capabilities: A study of China’s ICT technologies. *Journal of Science and Technology Policy in China*. 4 (3),195 – 213.
- Author, Graham, Ian, Stewart, James and Williams, Robin (2013) Standards Development as Hybridization. *International Journal of IT Standards and Standardization Research*, 11(2), 34-45.
- Star SL, Ruhleder K. (1996) ‘Steps toward an ecology of infrastructure: design and access for large information spaces’ *Inf Syst Res.*;7(1):111–34.
- Steen, H.U. (2011) Limits to the regulatory state in the rule-making of digital convergence: A case study of mobile TV standards governance in the European Union and China. *Technology Analysis and Strategic Management* 23 (7), 759–72.
- Stewart, J. Author, Wang, C. and Graham, I. (2011) From 3G to 4G : standards and the development of mobile broadband in China. *Technology Analysis and Strategic Management*, 23 (7), 773–788.
- Suttmeier, P., & Yao, X. K. (2004). China’s post-WTO technology policy: Standards, software, and changing nature of techno-nationalism, NBR special report No. 7.
- van den Ende, J., van de Kaa, G., Den Uijl, S., and De Vries, H.J. (2012) The paradox of Standard Flexibility: The Effects of Co-evolution between Standard and Interorganizational Network. *Organization Studies* 33 (5,6), 705-736.

- Tidd, Joe (ed.) (2010), *Gaining Momentum: Managing the Diffusion of Innovations, Series on Technology Management: Volume 15*, London : Imperial College Press.
- Ure, John (2007) China Standards and IPRs (*Working Paper for the EU-China Trade Project*, April 2007). <http://www.trpc.com.hk>.
- van de Kaa, Geerten, Greeven, Mark & van Puijenbroek, Gido (2013) Standards battles in China: opening up the black box of the Chinese government, *Technology Analysis & Strategic Management*, 25(2), 567-581.
- van der Vleuten, E. (2004). Infrastructures and societal change. A view from the large technological systems field. *Technology Analysis & Strategic Management* 16 (3), 395-414.
- van der Vleuten, E. (2006) Understanding network societies: Two decades of large technical system studies. in E. van der Vleuten and A. Kaijser (eds). *Networking Europe: Infrastructural integration and disintegration*. Sagamore Beach. Mass.: Science History Publications.
- van der Vleuten, E. (2009). Large Technical Systems, in Olsen, JanStig Andur Pedersen and Vincent F. Hendricks (eds.) *A Companion to the Philosophy of Technology*, (pp. 218-223) Wiley–Blackwell.
- Williams, Robin and Pollock, Neil (2012) Research Commentary—Moving Beyond the Single Site Implementation Study: How (and Why) We Should Study the Biography of Packaged Enterprise Solutions. *Information Systems Research*. 23(1), 1-22.
- Xia, Jun (2011) The third-generation-mobile (3G) policy and deployment in China: Current status, challenges, and prospects. *Telecommunications Policy*. 35(1), 51–63.
- Yu, Jiang (2011) From 3G to 4G: technology evolution and path dynamics in China's mobile telecommunication sector, *Technology Analysis & Strategic Management*, 23(10), 1079-1093.

## Notes

---

<sup>i</sup> Details removed for review.

<sup>ii</sup> See “What’s The Difference Between FDD And TDD?” ElectronicDesign 30.06.2012,  
<http://www.electronicdesign.com/communications/what-s-difference-between-fdd-and-tdd>.

<sup>iii</sup> A discussion with the ZTE delegate taking part in the panel discussion in China-EU ICT  
standards workshop (Beijing 20 April 2009).

<sup>iv</sup> Telephone interview with Prof Wu, Academician of Chinese Academy of Engineering and a  
renowned strategist for national telecommunications and information systems (April 2009).

<sup>v</sup> TDIA had 50 members then, according to Chinese Telecommunication Network 114,  
<http://www.c114.com.cn/news/22/c5355.html>, last accessed on 10.05.2018.

<sup>vi</sup> Pressure for stronger state intervention grew where entrenched global innovation systems and  
value chains were seen as unfavourable for Chinese players.